Ontology-based interpretation of arrow symbols for visual communication

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Arrow symbols are an essential tool for visual communications. Although arrow symbols look familiar and intuitive, diagram readers have to interpret the semantic role of each arrow symbol in the diagram, since arrow symbols are versatile and often used multi-purposely without specification. This paper reveals that such interpretation requires background knowledge about certain characteristics of the elements referred by the arrow symbol in the diagram. Then, this paper demonstrates that such knowledge can be computationally derived from general-purpose ontologies. This analysis gives an insight into the appropriate use of arrow symbols in visual communication and will contribute to the development of more intelligent pen-based systems.

Keywords: Arrow symbols; Pen-based system; Diagram interpretation; Ontology

1. Introduction

Arrow symbols are paramount for visual communication. They are used multi-purposely to represent directions, movements, relations, orders, and so forth (Horn 1997, Kurata and Egenhofer 2005a). In geographic context, arrow symbols are used on maps to visualize individual trips, mass flows such as migrations, spatial interactions, and vector fields (Bertin 1983), or simply highlight or label a certain location. Arrow symbols are powerful and vital visualization tools, since arrow symbols enable people to illustrate dynamic processes even in a static diagram (Monmonier 1990, MacEachren 1995).

Since arrow symbols are versatile and often used multi-purposely even in a single diagram without specification (Tversky *et al*. in press), it is up to the diagram readers to interpret the semantic roles of arrow symbols by themselves (Figure 1) This interpretation is sometimes difficult for people without well-crafted context (Tversky *et al*. in press) and also for computer agents without background knowledge (Kurata and Egenhofer 2005a), although arrow symbols look familiar and intuitive. For instance, Figure 2 is ambiguous by itself and has a risk of being interpreted in an unintended way. We have been, therefore, studying the mechanism of visual communication by arrow symbols through modelling the interpretation process of arrow symbols (Kurata and Egenhofer 2005a, 2005b, 2006). To understand the process of arrow interpretation and the background knowledge required for the interpretation will give an insight into the appropriate use of arrow symbols in visualization, which minimizes the risk of misunderstanding. In addition, this interpretation model will contribute to the development of more intelligent pen-based systems, where the user will be able to sketch or annotate their ideas and knowledge on the computer screen using arrow symbols multi-purposely (Figure 3).

Our previous studies demonstrated that the semantic roles of arrow symbols are tightly related to the pattern of syntactic structures, i.e., alignment of icons or text around

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each arrow symbol (Kurata and Egenhofer 2005b) and topological relations between arrow symbols (Kurata and Egenhofer 2006). The syntactic information alone, however, leads at times to ambiguous or even invalid interpretations. Thus, this paper introduces a new approach for the interpretation of arrow symbols with the aid of background knowledge in addition to the syntactic information. Section 2 summarizes our previous work and its deficiencies. Section 3 proposes the use of background knowledge about the characteristics of arrow-related elements for the interpretation. Section 4 demonstrates how to derive such knowledge from general-purpose knowledge bases. Finally, Section 5 concludes the discussion.

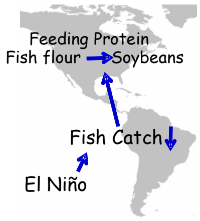


Figure 1. An arrow diagram illustrating the consequences of El Niño Effect, where arrow symbols are used multi-purposely without specification to capture causal relation, increase/decrease, and shift.

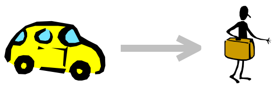


Figure 2. An ambiguous arrow diagram, which can be interpreted as 'the car approaches to the person', 'the person leaves the car', or 'the car is assigned to the person'.

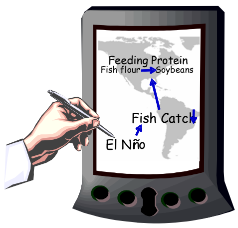


Figure 3. An image of future pen-based systems, where the user can explain their idea or knowledge to the computer by sketching or annotating on the screen, as people often do on papers in face-to-face communication.

2. Syntax-based interpretations

Usually, the meaning of an arrow symbol is established when the arrow symbol *refers to* (i.e., originates from, points to, traverses, or goes along) other elements around the arrow symbol. The relative position of these elements around the arrow symbol is critical for the semantics (Kurata and Egenhofer 2005a). The combination of arrow symbols and the elements to which the arrow symbols refer to is called an *arrow diagram* (Kurata and Egenhofer 2006). Then, the elements in an arrow diagram are called the *components* of the arrow diagram. The components are classified into the following five types (Figure 4):

- *objects* (*O*) take an action,
- *events* (*E*) occur in time and are characterized by a set of changes,
- *locations* (*L*) are positions in space,

- *moments* (*M*) are positions in time, and
- *notes* (*N*) are descriptions that modify other component or the arrow symbol.

Since the components are located either in front of the arrow's head, behind the arrow's tail, or along/on the arrow's body, an arrow symbol identifies three different areas where the components can be located, which are called *component slots*. Kurata and Egenhofer (2005b) considered that the type of components in the three slots form a syntactic pattern. This pattern is described as ([*O*|*E*|*L*|*M*|*N*]*, [*O*|*E*|*L*|*M*|*N*]*, [*O*|*E*|*L*|*M*|*N*]*), where three elements in parentheses indicate the types of components in tail, body, and head slot, respectively, and [*x*]* means a sequence of any number of *x* or empty, and *x*|*y* means *x* or *y* but not both (Figure 4).

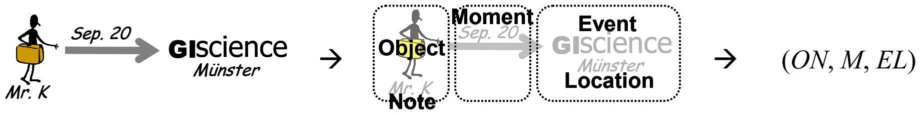


Figure 4. An arrow diagram may have five types of components in three slots, which forms a syntactic pattern.

Kurata and Egenhofer (2005b) distinguished the semantic roles of arrow symbols into four types: *property*, *annotation*, *action*, and *association*. An arrow symbol for *property* modifies a component by itself (e.g., direction and vector). An arrow symbol for *annotation* connects two components such that one component is modified (labelled) by another component. An arrow symbol for *action* represents the motion of one component, which may trigger or be triggered by an interaction with another component. Finally, an arrow symbol for *association* illustrates the presence of certain relation between components by connecting them (e.g., order and asymmetric relation).

Kurata and Egenhofer (2005b) identified the syntactic requirements for assigning each semantic role to an arrow symbol, as well as the syntactic conditions for adding optional components to the arrow diagram. These two syntactic rules determine a set of syntactic patterns that may correspond to each semantic role. Consequently, possible semantic roles of an arrow symbol can be deduced, although not always uniquely, from the syntactic pattern associated to the arrow symbol. For instance, among 215 patterns of *simple arrow diagrams*, which contain at most one component in each slot, 81 patterns correspond to exactly one semantic role, and 52 patterns correspond to two or three roles (Figure 5). This means that in the 81 patterns of arrow diagrams the arrow's role is uniquely determined, whereas the 52 patterns of arrow diagrams need further information in order to narrow down the candidates.

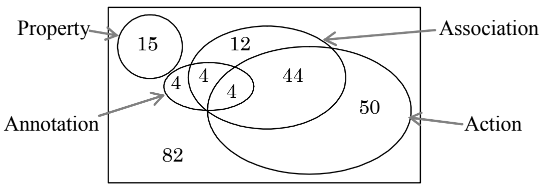


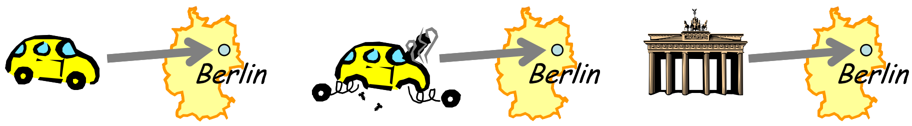
Figure 5. The correspondence between 215 structural patterns of simple arrow diagrams and possible semantic role of arrow symbols in these diagrams (Kurata and Egenhofer 2005b).

3. Beyond a purely syntax-based approach

In order to construct a meaningful arrow diagram, the components must have certain characteristics associated with them. For instance, Figures 6*a*–*b* illustrate the scenario 'the car goes to Berlin' only if the car is movable. While such knowledge may depend on the instances depicted in the arrow diagram, in most cases it can be determined already at the class level. For example, cars are typically considered moveable, unless additional information (such as 'a car without wheels') would negate a car's mobility. In general, in order to assign the previous four semantic roles to arrow symbols, the elements with the following characteristics are necessary:

- *Action* requires an element that moves, called the *mobile subject*.
- *Property* requires an element that has a property related to orientation (and thereby represented by arrow's orientation), called the *orientation-related subject*.
- Annotation requires an entity and a description that modifies the entity, called the *labeled-subject* and *label*, respectively.
- *Association* requires two entities that are linked under a certain associating rationale.

Normally, elements with these characteristics are explicitly drawn in the diagram as a component, such that the presenter's intension is correctly communicated to the readers (although these elements may be omitted if they are contextually evident). The use of arrow symbols, therefore, encodes such characteristics as *mobility* on some components in the diagram. Not all components carry such characteristics, however. For instance, a huge construction such as the Brandenburg Gate, or a geographic location like Berlin, are typically not considered a mobile subject; therefore, Figure 6*c* does not capture an action, because the arrow symbol for action has to impose the characteristic of a mobile subject on either the Brandenburg Gate or on Berlin. Instead, Figure 6*c* captures the relation Brandenburg Gate and Berlin. In general, an arrow symbol does not qualify for a semantic role *r* if the use of an arrow symbol for *r* has to impose an impossible characteristic on one of the components.



(*a*) (*b*) (*c*)

Figure 6. Arrow diagrams with the same syntactic pattern (*O*, –, *L*), illustrating (*a*) an action, (*b*) no action due to the immobility of the broken car, and (*c*) no action due to the (immobile) Brandenburg Gate.

Usually, the presenter and readers of an arrow diagram share the knowledge about possible characteristics of components and, therefore, they can communicate the diagram without misunderstanding. Lack of such knowledge, however, results in the failure to remove impractical interpretation, such as 'the Brandenburg Gate goes to Berlin' (Figure 6*c*), which has no problem from a syntactic viewpoint. This ambiguity indicates the need for common-sense knowledge about the world for the interpretation of arrow symbols. Thus, in order to model this interpretation process, we employ the knowledge extracted from *ontologies* (Guarino, 1998), which are formal models of the people's conceptualizations about the world. A large variety of ontologies has been developed to model and formalize the knowledge shared by various communities of different domains. An ontology typically consists of vocabularies, properties and operations associated with each vocabulary, and relations between the vocabularies. Those relations usually include subsumption and metonymy relations (i.e., *is-a* and *part-of* relations), thereby establishing hierarchical structures between vocabularies.

4. Ontological knowledge for mobile subjects

This section demonstrates that the knowledge about possible characteristics of components can be computationally derived from an ontology. For generality, we use an upper ontology, which is typically used as a foundation of various domain ontologies. Here we use *WordNet* (Fellbaum, 1998), which is a semantic lexicon for the English language and a well-known upper ontology, in order to derive the knowledge about the possibility of entities to be a mobile subject.

A component must be movable if it is considered a mobile subject. Mobility is often employed in the definition of an entity class as one of its essential characteristics. For instance, WordNet defines *animal* as 'living organism characterized by voluntary movement'. This definition clearly indicates that, *animals* are movable. The mobility of a class is also determined from the operations associated with the class. For instance, *ball*, which is defined as 'a round object that is hit or thrown or kicked in games', is associated with such operations as *hit*, *throw*, and *kick*. Since *hit*, *throw*, and *kick* are subclasses of the transitive verb *move* (Figure 7*a*), the ball is considered movable.

Mobility is inherited from upper classes to lower classes. Consequently, any subclasses of *animal*, such as *dog* and *cat*, and any subclasses of *ball*, such as *soccer ball* and *tennis ball*, are also considered movable (Figure 7*b*). This is a great benefit of using an ontology for the judgment of components' mobility.

If the superclass of class *c* is movable, but *c* itself is characterized by its immobility, *c* is immovable and immovability would be inherited to *c*'s subclasses as well. For instance, a car without wheels is immovable (Figure 6*b*), although its superclass, a car, is movable. A truck without wheels, as a subclass of the car without wheels, is then immovable as well.

In general, class *c* qualifies as a mobile subject if

- *c* is characterized by its mobility in its definition,
- *c* has an operation *move* (in the sense of either a transitive or an intransitive verb) or a subclass of *move* (Figure 7*a*), or
- *c*'s parent qualifies as mobile subject and *c*'s definition does not characterize it immobile (Figure 7*b*).

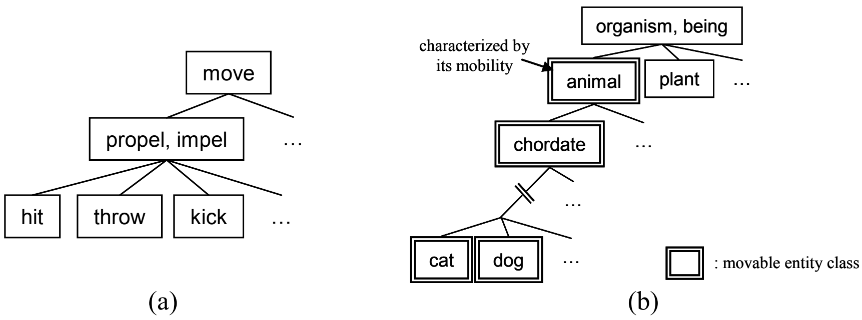
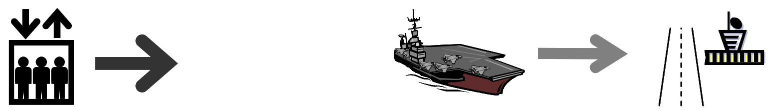


Figure 7. (*a*) Hierarchy of an operation *move* and its subclasses and (*b*) hierarchy of *animal* and its super/subclasses with inheritance of mobility.

A difficulty arises when determining the lack of mobility (i.e., immobility), since immobility is less recognized as an essential characteristic of an entity class than mobility. A realistic solution is to adopt the closed world assumption (Reiter, 1987), that is, to assume that lack of knowledge about its mobility indicates its immobility. For instance, the Brandenburg Gate is considered immovable, because the *Brandenburg Gate* and its super classes (*memorial/monument*, *structure/construction*, *artifact/artifact*, and so forth) are not characterized by their mobility and have no operation related to *move*.

Such inferences rely on the completeness of the ontology and have a risk of unexpected consequences. For example, from WordNet one would misjudge a *cloud* in the sky to be immovable due to the lack of knowledge about its mobility. Since this problem arises from the incompleteness of WordNet, the use of another ontology may actually reveal the mobility of a cloud. Indeed, *Dictionary.com*, defines *cloud* as ‘a large moving body of things in the air or on the ground’, which clearly indicates the cloud’s mobility. Such discrepancies among ontologies imply it may be necessary for error-free judgments about the mobility of components to employ and mine multiple ontologies.

Strictly speaking, mobility/immobility of an entity may be subject to direction and field. For example, an elevator can move only vertically and an aircraft carrier can move only on a (large) water surface. Consequently, Figure 8*a* cannot be interpreted as ‘an elevator goes to the right’ and Figure 8*b* cannot be interpreted as ‘an aircraft carrier goes to an airport’s landing field’. Such interpretations require the information about the components’ direction-dependent and field-dependent mobility, which is often derivable from the ontology as well. For instance, WordNet defines *elevator* as ‘a lifting device consisting of a platform or cage that is raised and lowered mechanically’. The two operations associated with the elevator, *raise* and *lower*, implicitly indicate its movable direction. Similarly, the mobility of an aircraft carrier on the water surface is derivable from the definition of its superclass, a *vessel*—‘a craft designed for water transportation’.



(*a*) (*b*)

Figure 8. Arrow diagrams with a restriction on their interpretations: (*a*) due to the elevator's direction-dependant mobility the diagram cannot be interpreted as ‘the elevator goes right’ and (*b*) due to the carrier's field-dependent mobility the diagram cannot be interpreted as ‘the aircraft carrier moves to the landing field’.

Mobility of a component may also be influenced by the mobility of its container and foundation, if exists. For instance, like the Brandenburg Gate, the Liberty of Freedom is typically immovable, although it once travelled across the Atlantic Ocean by ship (i.e., a mobile container). Similarly, a house is typically immovable, but it may move by a landslide of the site (i.e., the foundation becomes a moveable surface). Containers and surfaces are important concepts of image schemata (Johnson, 1987). The role of containers and surfaces in modifying otherwise immobile items is a topic for future research.

5. Conclusion

This paper reported on our ongoing study about the mechanism of visual communication by arrow symbols. They are essential for representing, analyzing, and communicating spatio-dynamic information. The use of arrow symbols, however, involves risk of misunderstanding due to their polysemy. This paper revealed that background knowledge about the characteristics of arrow-related elements, such as mobility, is important for the interpretation of arrow symbols. This suggests that for successful communication the presenter should think carefully whether the expected readers commonly have such background knowledge and, if not, gives such knowledge to the readers in the caption or document. Also, it is recommendable to use different styles of arrow symbols for different semantic role, such that their differences become visually distinctive by, for instance, their arrow-head shapes, colors, textures, and widths.

This paper demonstrated how to determine the mobility of arrow-related elements with the aid of ontologies. It remains a future question how to derive knowledge about other characteristics of arrow-related elements with the aid of ontologies and to apply this knowledge to the interpretation of arrow symbols.

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